DOI: 10.21062/mft.2024.006 http://www.journalmt.com

Measurement of the Dynamic Load of the Cervical Vertebrae of the Human Spine – Pilot Experiment

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The article deals with the experimental measurement of the load on the cervical vertebrae when driving a passenger car over bumps. The measurement was done experimentally. The load on the human spine was measured in the area of the C7 cervical vertebra and also in the area of the top of the head. Vehicle crossings over speed bumps. The measurement was carried out at different crossing speeds and at different heights of speed bumps. Three-axis acceleration sensors were placed on selected parts of the vehicle and on the human body. The proposed measurement methodology was verified by the conducted pilot experiment for the possibility of conducting further experiments. The results of the work showed that the crew of vehicles in road transport is more stressed than previous scientific findings indicate.

Keywords: Dynamic load, Human, Spine, Automobile, Measurement, Experiment

1 Introduction

Dynamic loading of the musculoskeletal system and the transfer of force effects to the human body is a worldwide problem. The main focus was on the most common causes of severe injuries to the head, chest and spine.

As early as the 1970s, biomechanics became interested in damage to the body as a result of external mechanical causes. These were mainly accidents in traffic and during sports. There has been an effort to increase the prevention of these accidents. The main attention was focused on the most common causes of severe head, chest and spine injuries.

Injuries associated with spine and spinal cord injuries are a serious problem today. The cervical region is the most vulnerable part of the spine due to its significant mobility, which is unfavorably applied in the event of a high-impact injury. The frequency of cervical spine injuries has been increasing recently, especially in traffic accidents (up to 45%), jumping into water and falls (up to 20%), sports activities (up to 15%).

Vertebrogenic disorders (Dylevský 2009) are one of the most commonly reported causes of pain that afflicts people today. People are exposed to dynamic shocks, for example, when driving in a road vehicle when driving over bumps/obstacles. We often encounter the problem of vibration in both wheeled and rail vehicles. Reducing the transmission of dynamic shocks to a person is solved by the vehicle's suspension system, respectively shock absorbers and absorbers. The value of the generated and transmitted acceleration to the vehicle's occupant position is also reflected in driving safety and also in the driving characteristics of the vehicle. From a short-term and long-term point in time, also on the locomotor apparatus of the vehicle crew (immediate injuries or increasing the probability of developing an illness). Neck injuries are mostly caused by the inertia of the head caused, for example, when crossing a bump or when driving around a corner. The resulting kinetic energy acting on the cervical vertebrae is the product of speed and weight. This, of course, increases the likelihood of a neck or head injury. An interesting fact is that more injuries occur at slow vehicle speeds. As already mentioned, a large part of the force effects is absorbed by the suspension system of the vehicle, but a partial part is always transferred to the driver's seat of the vehicle. One-sided loading of the organism for a longer period of time results in an increase in the probability of injury. In exceptional cases, these loads can lead to the death of a person. The main goal of this experimental research was to measure the dynamic values that affect the driver and passenger in a passenger car when driving over bumps. The measurement was carried out experimentally in a real environment on a defined track at different driving speeds and different distribution of obstacles on the road. Acceleration sensors were used to measure the magnitude of the acceleration at the attachment point of the driver's and passenger's seat, at the seat under the buttocks, while the vehicle was driving. On a person at the point of the highest peak of the head and also on the cervical vertebra C7. The result of the work was a comparison of the measured values on the passenger of the vehicle between people with the values that are reported in the professional literature.

Values of selected acceleration values (Ravnik, 2002) that affect people in transport vehicles:

- passanger car 0.20 to 0.75 m.s^{-2}
- bus 0.40 to 0.80 m.s^{-2}
- tractor 0.40 to 2.80 m.s^{-2}
- forklift truck 0.40 to 2.00 m.s^{-2}
- locomotive 0.30 to 0.60 m.s^{-2}
- tank 1.50 to 3.50 m.s^{-2}
- ship 0.50 to 0.70 m.s^{-2}
- helicopter 0.10 to 1.55 m.s^{-2}

A large number of scientific works (e.g. Jadhao and Patil, 2017; Špirk, 2015; Kleber et al., 2007) deal with solving the dynamics of mechanical systems, both wheeled and rail vehicles.
Also, a large number of studies deal with increasing the passive safety of wheeled vehicles. Important works include, for example, Bittner et al., 2019; Lopot et al., 2019; Chalupa et al., 2019 and many others.

Many studies (e.g. Alperowitch-Najenson et al., 2010; Bovenzi 2002; Jandák, 2007; Robb and Mansfield, 2007) also report that exposure of the body to long-term vibrations causes an adverse response in the human organism that can lead to irreversible damage. People are exposed to such vibrations, for example, by driving in transport vehicles, but also during work activities in the construction, engineering or metallurgical industry.

All of the work mentioned above was used to create the measurement methodology the connection of the measuring chain of sensors and amplifiers. The works that dealt with experimental investigations in the field of dynamic loading were also used to create the measurement methodology (e.g. Chmelař et al. 2020; Skalický et al., 2021, Flek et al., 2021; Lopot et al., 2021 and Ponikelský et al., 2021)

It is obvious that the dynamic load during the driving of the vehicle causes a load on the crew which can affect their health.

The aim of this work was to find out what acceleration values are transferred from the vehicle structure to the body of the passenger, or the head and the C7 cervical vertebra when the vehicle passes over obstacles at different vehicle speeds.

2 Measurement methodology

The main goal of the initial experiment was to measure the maximum acceleration values in selected parts of the passenger car and on the human body and to verify them with the conclusions of the research work of Ravnik (2002). The measurement was carried out on a straight road in a Škoda Octavia passenger car (year 2016).

The measurement was carried out by driving a passenger vehicle on a straight road path on which obstacles were placed. Excitation of the vehicle was carried out by driving over obstacles with a height of 50 mm (Fig. 1). Acceleration values were recorded on the seat attachment, under the driver's buttocks, and on the C7 vertebra (vertebrae cervicales) and the head.

In Fig. 1. the distribution of deceleration thresholds on the test track is shown. The measurement also served to verify the design of the measurement methodology and evaluate the appropriateness of the connection of measurement chains and the processing of measured data for the possibility of further experimental measurements.

The obstacles were 15 meters apart (sufficient distance to dampen the vibrations of the vehicle). The first crossing of the obstacle was made only with the right wheel. The second excitation was caused by crossing an obstacle with the left wheel and the third by both wheels simultaneously.

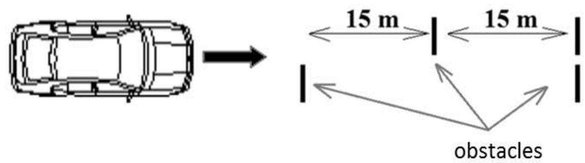

Fig. 1 *Schematic layout of obstacles on the road*

Fig. 2 *Demonstration of driving a passenger car through speed bumps*

5 obstacle crossing speeds were chosen and the sensed quantities were measured in the first five runs over bumps on the driver. For the next five runs, the measurement was shifted to the passenger in the vehicle. Experimental measurement of acceleration magnitudes while driving in a vehicle was carried out in the number of variants = 10 - see Table 1.

Tab. 1 *Variants of performed measurements*

speed	10 km/h	20 km/h	30 km/h	40 km/h	50 km/h
driver	E1	E2	E3	E4	E5
passenger	E6	E7	E8	E9	E10

a) vehicle wheel *b) the body of the vehicle*

Fig. 3 *Markers placed on the vehicle*

Fig. 4 *Acceleration sensor located under the driver's buttocks*

Figure 3 shows the markers that served to determine the current speed of the vehicle using the Redlake HG 100 speed cameras.

The magnitudes of acceleration were measured using 3-axis acceleration sensors, which were placed at the attachment point of the seat, on the seat under the person's buttocks (Fig. 4), at the highest point of the head, and at the point of the person's back at the cervical vertebra C7 (Fig. 5).

The speed of the passenger car was also recorded by the Qualisys camera system. Using four infrared cameras, the movement of markers placed on the vehicle at the wheel and body locations was recorded. A total of 9 markers were placed to measure the current speed of the vehicle. The marker that was placed in the center of the wheel is shown in Fig. 3a.

The results from the experiments were also processed graphically. Dewesoft X3 and MS Excel software were used.

In Tab. 2 shows the highest values of acceleration in the horizontal direction when crossing obstacles at precisely determined speeds detected by the driver (person) of a passenger car vehicle (measurement variants E1 to E5).

Fig. 5 *Acceleration sensors placed on the proband - head and vertebra C7*

Tab. 2 *Maximum acceleration values measured on the driver – variants E1 to E5*

variant	speed [km.hod^{-1}]	Maximum values of vertical acceleration [m.s^{-2}]			
		seat	under the buttock	C7	head
E1	10	0.556	1.304	0.499	0.557
E2	20	0.842	1.514	0.775	0.604
E3	30	2.350	1.79	1.351	1.109
E4	40	3.178	2.198	1.490	1.179
E5	50	2.875	2.756	1.512	0.916

From the measured values of acceleration in the vertical direction, it is clear that the highest values of acceleration were obtained with the measurement variant labeled E5 when crossing an obstacle on the road at a speed of 50 km.h^{-1}. The highest value of vertical acceleration on the human body was measured at the C7 vertebra with an acceleration value of 1,512 m.s^{-2}.

In Tab. 3 shows the maximum acceleration values in the vertical direction of crossing obstacles measured on the passenger (person) of a passenger car vehicle (measurement variants E6 to E10).

Tab. 3 *Maximum acceleration values measured on the front passenger – variants E6 to E10*

variant	speed [km.hod^{-1}]	Maximum values of vertical acceleration [m.s^{-2}]			
		seat	under the buttock	C7	head
E6	10	1.156	0.853	0.671	0.784
E7	20	2.049	1.133	0.772	0.845
E8	30	2.542	1.240	0.969	0.965
E9	40	3.608	1.870	1.236	1.125
E10	10	1.156	0.853	0.671	0.784

For variants E6 to E10, the highest vertical acceleration values were again measured at vehicle speeds of 50 km.h^{-1}. The highest value of vertical acceleration on the human body was measured at the C7 vertebra with an acceleration value of 1.452 m.s^{-2}.

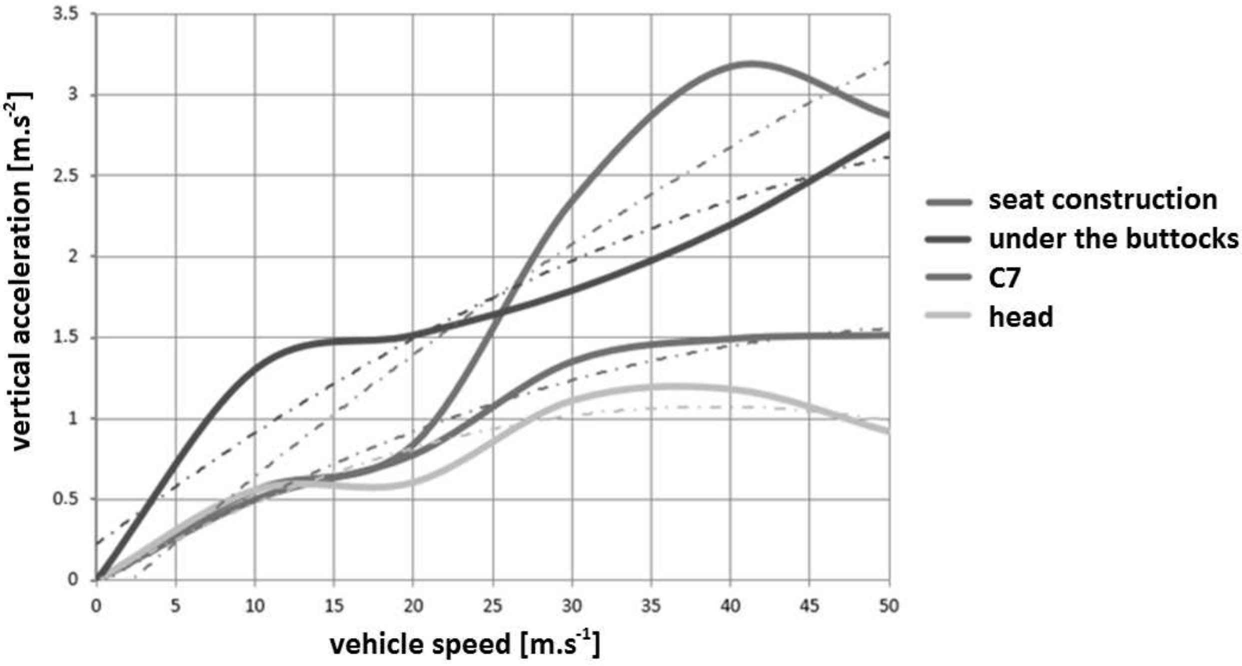

Fig. 6 *Driver - magnitude of acceleration at vehicle speed - variants E1 to E5*

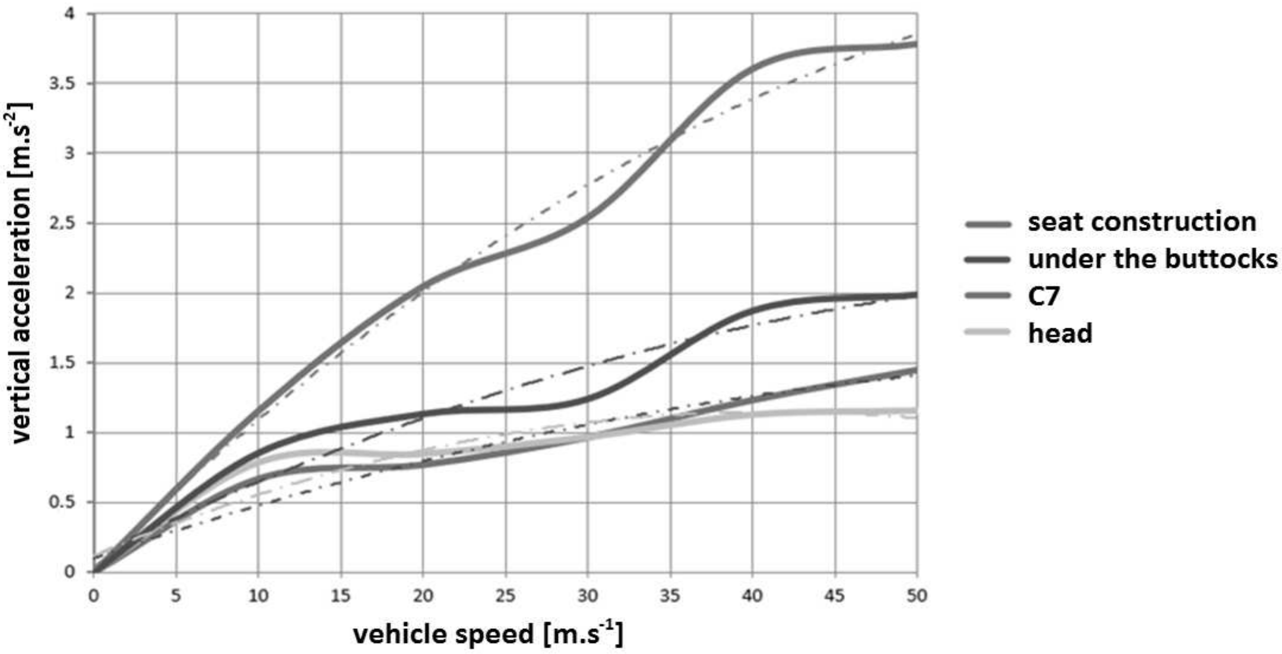

Fig. 7 *Passenger - magnitude of acceleration at vehicle speed - variants E6 to E10*

The graphs shown in Fig. 6 and 7 show increases in vertical acceleration values when crossing a bump at a higher vehicle speed. It is clear from the graphs that it will be necessary to make more unevenness crossings at the same speed, which we will be able to evaluate statistically and the resulting dependencies will be more accurate.

In the following figures (fig. 8 and 9) are graphs displayed using the Dewesoft X3 program. The graphs show the crossing over ordered combinations of retarder locations. The left part of the graph corresponds to crossing an obstacle with the right wheel of the vehicle, the center of the graph belongs to crossing the left wheel of the vehicle, the right part of the graph shows the magnitude of the acceleration when crossing the obstacle with both wheels at the same time.

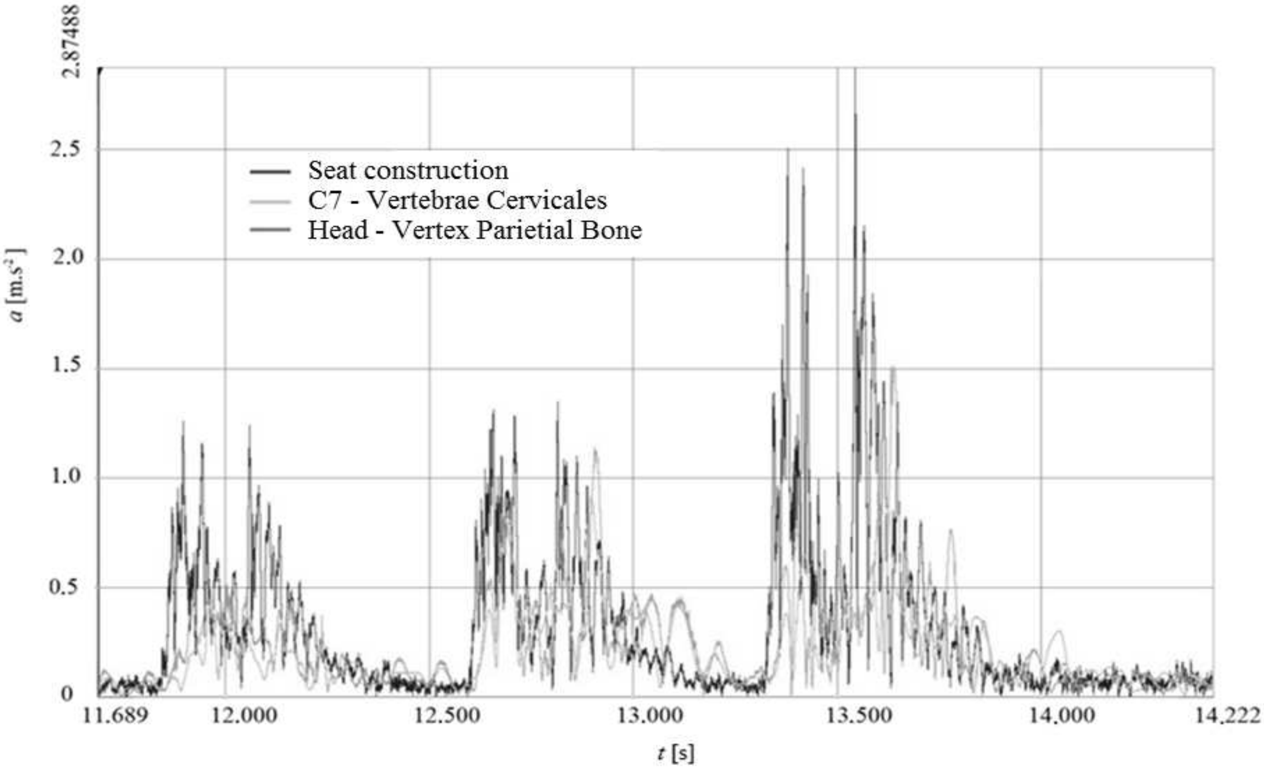

Fig. 8 *Driver - magnitude of acceleration for crossing three obstacles on the road - variant E5*

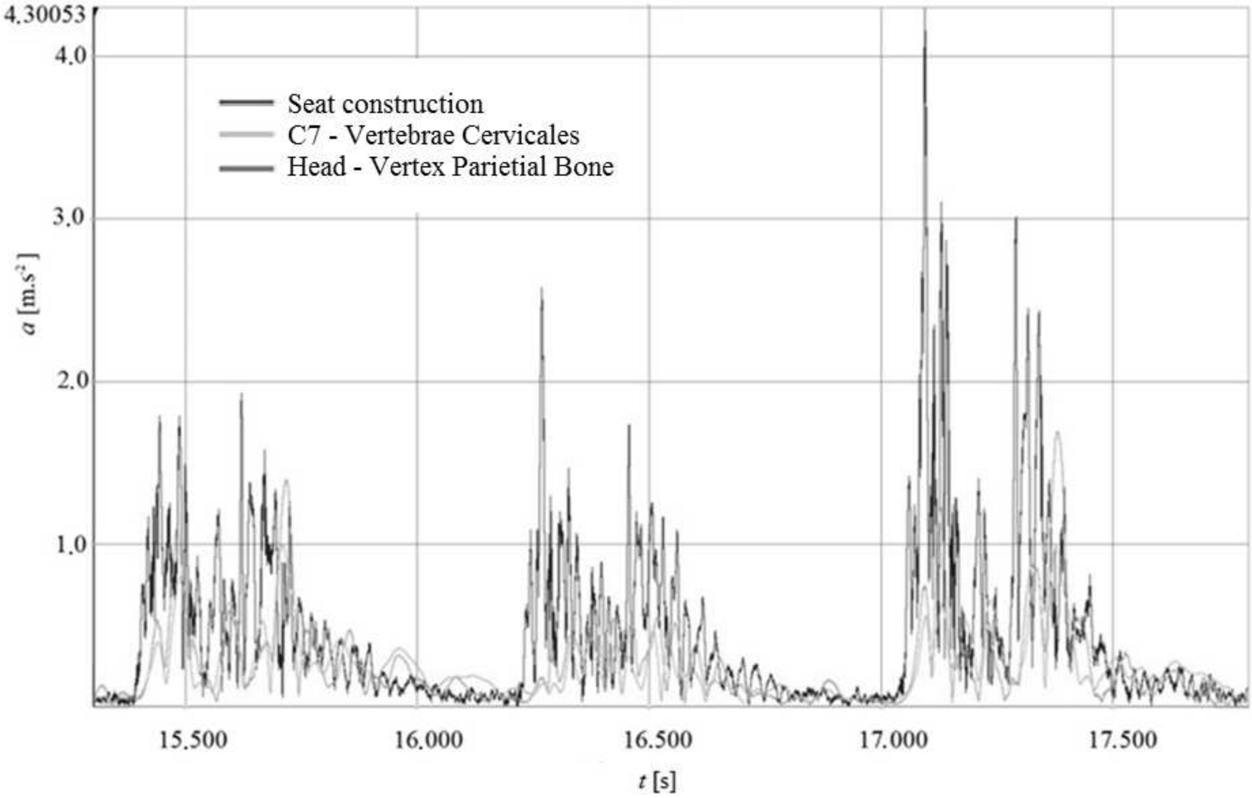

Fig. 9 *Passenger - magnitude of acceleration for crossing three obstacles on the road - variant E10*

From the graphs shown in Fig. 8 to 9 it is evident that the values of the vertical acceleration take on the highest values when crossing the obstacle on the test track with both wheels at the same time (right part of the graph).

The values of the dynamic load in the vertical direction of the crew of a passenger car when crossing bumps at different crossing speeds were obtained through a pilot experiment.

The measurement was performed on the driver of the vehicle and in the passenger seat. The assumption that a person is exposed to the highest values of vertical acceleration when driving a vehicle over obstacles with both wheels at the same time was verified.

In the area of the C7 cervical vertebra, an acceleration of 1.512 $m.s^{-2}$ was measured in the driver's seat when crossing obstacles at the highest speed of the vehicle. At the point of the highest peak of the head was the highest acceleration of 1.179 $m.s^{-2}$.

The greatest acceleration in the vertical axis also affected the person in the seat of the passenger in the vehicle when the vehicle crossed the highest obstacle crossing speed (50 $km.h^{-1}$). The greatest acceleration in the area of the C7 vertebra was measured with an acceleration of 1.452 $m.s^{-2}$, an acceleration of 1.153 $m.s^{-2}$ was measured on the head.

It was found that the hypothesis of Ravnik (2002) states lower burdening values of the acceleration of the human body in a passenger car. Therefore it is necessary to deal with this issue in more detail.

The pilot experiment verified the suitability of the proposed solution methodology for collecting the necessary values and the processing method.

The following conclusions were drawn from the pilot experiments for further investigation:

- The proposed measurement methodology was verified as suitable for further experimental measurements.
- The compiled measurement chain and the data processing procedure were recognized as valid.
- Dynamic magnitudes of acceleration transmitted to the driver's body while driving in a road vehicle are higher than those reported by Ravnik (2002).
- It was determined that for the summary measurement it would no longer be necessary to evaluate the acceleration under the person's buttocks. Repeated measurements will be made on the seat of a passenger car (taken as the main input for transferring acceleration to a person). The measurement will include the measurement of the vertical acceleration at the point of the wheel suspension (under the shock absorber) and at the point of the

vehicle body (above the shock absorber). The acceleration transmission chain for the summary measurement will be: wheel suspension - vehicle body - seat frame - C7 cervical vertebra - crown of the head.

- It was confirmed that the magnitudes of the acceleration gradually decrease from the point of excitation to the body of the vehicle crew due to the damping capabilities of the individual parts of the vehicle and the human body itself.
- For the summary experiment, crossings of inequalities will be performed in multiple repetitions (increasing the quality of the statistical evaluation of the data).
- Vehicle speeds will be set using cruise control and measured by the Qualisys and GPS system for better measurement.
- The distribution of obstacles at a distance of 15 m was found to be sufficient for attenuation of the previous excitation - it will be left in the next measurement.
- Different sizes of obstacles (speed bumps) will be used for further measurements, driving will always be done by crossing the speed bumps with both wheels at the same time. 3 types of retarders with different heights will be used.
- The Dummy Hybrid III dummy will also be used in further measurements to verify the suitability of its use for research in laboratory conditions.

3 Conclusion

From the conducted experiments, the magnitudes of the accelerations affecting the vehicle crew during driving in a passenger car when passing over obstacles on the road were measured.

The driver was affected by the maximum acceleration when crossing the bump with both wheels of the vehicle at the same time. The highest acceleration values were measured at the highest speed of the completed crossings (50 km.h^{-1}). The acceleration at the C7 cervical vertebra was measured to be 1.512 m.s^{-2}, at the top of the driver's head 0.916 m.s^{-2}. The acceleration attenuation from the seat structure that was transferred to the seat area was 4.14%. In the area of the buttocks, an acceleration of 2.756 m.s^{-2} was transmitted to the driver, which was manifested by an acceleration on the C7 vertebra of 1.512 m.s^{-2} and on the head with a value of 0.916 m.s^{-2} . The stated value exceeds Ravnik's conclusions, the driver may be burdened by greater dynamic effects in the vehicle.

When driving in a car, the passenger is also affected by similar dynamic effects, which uniformly took on the highest values when the vehicle passed over obstacles at the highest selected speed with both wheels. On the head of the passenger (human), the rate of acceleration was even higher at 1.153 m.s^{-2}.

The results of the measurements showed the magnitude of the dynamic load that is transferred to the body of the passenger car crew when crossing bumps at gradually increasing crossing speeds. It was found that the magnitudes of the vertical acceleration that are transmitted to the body of the vehicle crew while driving a wheeled vehicle are higher than reported in the literature Ravnik (2002).

Acknowledgement

This research was financially supported by the internal grant of Krajská Zdravotní a.s. IGA IG7-217111026.

The presented study has been prepared with the support of the VAROPS project (DZRO VAROPS), University of Defence Brno, Czech Republic.

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